GigaTracker

Low Mass and Fast Timing Hybrid Silicon Pixel Detector

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On behalf of the NA62 GigaTracker working group

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Outline

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  - Detector Layout
- GigaTracker
  - Overview
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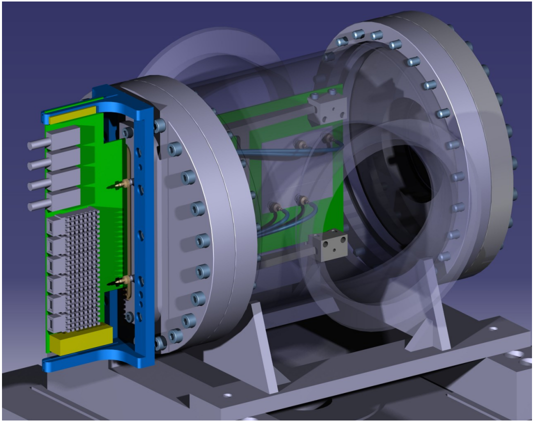
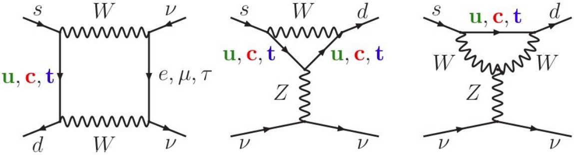
  - Readout Chip
  - Cooling
  - Mechanical integration
- Prototype
  - Laser Test Bench
  - Test Beam
- Summary



Outline

Theoretically very clean, sensitive to new physics



$$\mathrm{BR}\left(K^+ \to \pi^+ \nu \bar{\nu}\right)_{\mathrm{SM}} = \left(7.81^{+0.80}_{-0.71} \pm 0.29\right) \times 10^{-11}$$

$$\mathrm{BR}\left(K^+ \to \pi^+ \nu \bar{\nu}\right)_{\mathrm{E949}} = \left(17.3^{+11.5}_{-10.5}\right) \times 10^{-11}$$

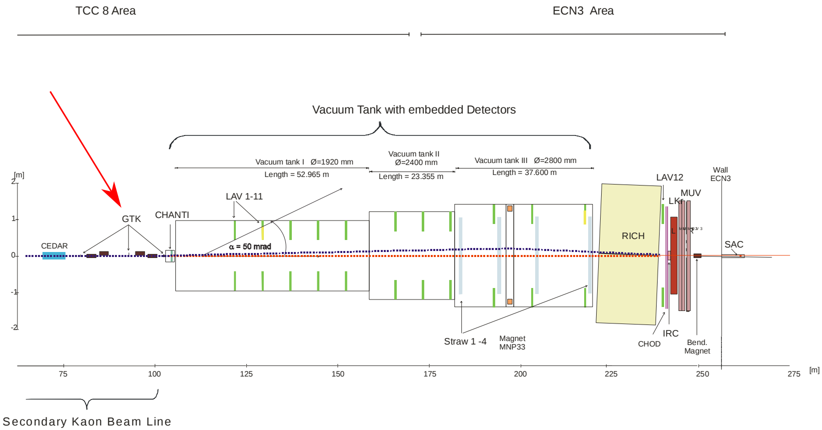
Our goal: detect $\mathcal{O}(100)$ $K^+ \to \pi^+ \nu \bar{\nu}$ with $\approx 10\%$ background over two years of data taking

Put constraints on new physics models and allows independent determination of $|V_{td}|$

*SM : Brod et al. (Phys. Rev. D, 83, 034030). E949 : Artamonov et al. (Phys. Rev. D, 79, 092004).

Layout - NA62

- Fixed target experiment @ CERN SPS,
- High intensity 75 GeV/c hadron beam, $\approx 6\%$ K^+, π^+ and p
- Particle identification, particle vetos, kinematic measurements

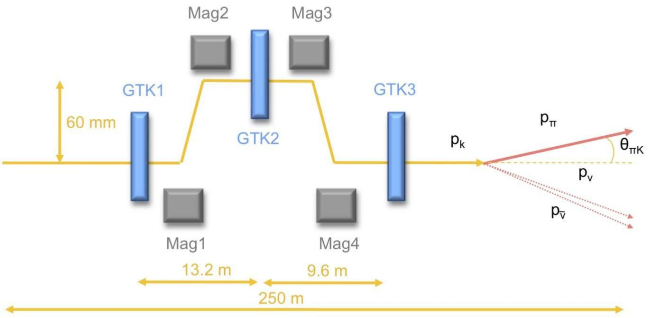


See also talk by Patrizia Cenci @ PXPS12

Layout - GigaTracker

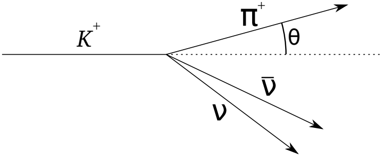
Key detector of the experiment

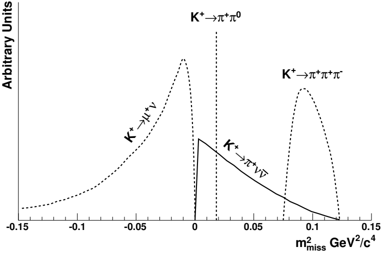
- Provides momentum, time of passage and direction of beam particles. Crucial for kinematic background rejection,
- Sees all beam particles, high and non-uniform rate, (1.3 $\mathrm{MHz/mm^2}$ in the center, 750MHz total),
- Has to be as thin as possible to avoid inelastic scatterings.



Kinematical Background Rejection

92 % of background can be separated from the signal by kinematic cuts





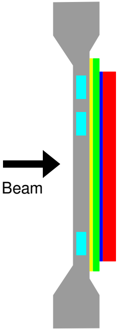
$$m^2_{\mathrm{miss}} = (p_k - p_\pi)^2 \approx m^2_{\mathrm{K}} \left(1 - \frac{|\mathbf{p}_\pi|}{|\mathbf{p}_{\mathrm{K}}|}\right) + m^2_\pi \left(1 - \frac{|\mathbf{p}_{\mathrm{K}}|}{|\mathbf{p}_\pi|}\right) - |\mathbf{p}_\pi||\mathbf{p}_{\mathrm{K}}|\theta^2_{\pi\mathrm{K}}$$

Impose requirements on GigaTracker:
$\sigma(p_k)/p_k \approx 0.2\%$, $\sigma(\theta_k) \approx 16\ \mu\mathrm{rad}$, $\sigma(t) < 200\ \mathrm{ps}$

Outline

GigaTracker Station Overview (I)

- Hybrid silicon pixel detector,
- $60 \times 27\ \mathrm{mm}^2$, 200 µm thick p-in-n sensor,
- 10 readout chips bump-bonded to the sensor,
- 18000 $300\ \mathrm{\mu m} \times 300\ \mathrm{\mu m}$ pixels,
- Total thickness $< 0.5\%\ X_0$,
- Operated in vaccum



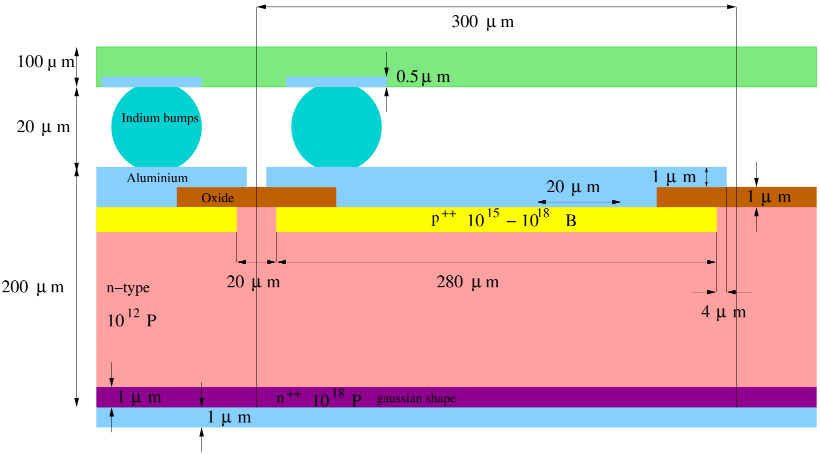
GigaTracker Station Overview (II)

Component	Thickness (μm)	Rad. length (% of X_0)
Sensor (Si)	200	0.22
Sn-Pb bump bonds (Sn-Pb)	20	0.001
Readout chip (Si)	100	0.11
Glue (Epoxy)	25	0.008
Cooling plate baseline (frame) (Si)	130 (0)	0.13 (0)
Total	475 (375)	0.469 (0.339)

The stations are easily swappable as they will be replaced during the experiment lifetime to cope with radiation damages

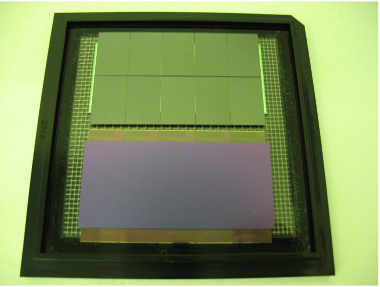
Sensor

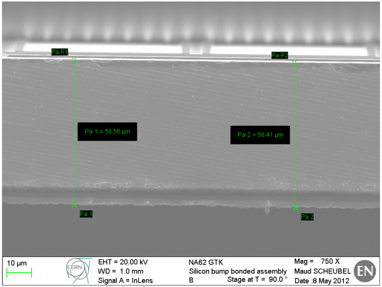
200 $\mu\mathrm{m}$ p-in-n sensor, operated over depleted ($V_{\mathrm{bias}} > 300\ \mathrm{V}$)



Bump Bonding

Thinning and bonding studies on dummy components at IZM (Berlin, Germany)





Readout chips thinned to 58 µm !

Readout Chips Layout

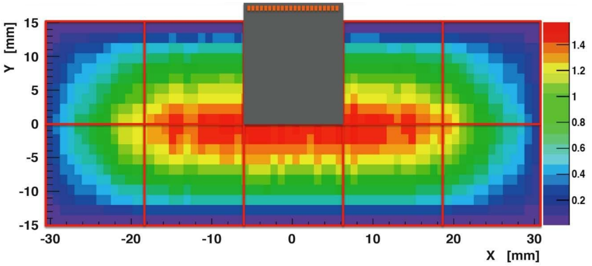


Figure: Beam intensity $(\mathrm{MHz/mm^2})$

This design allows to spread the rate over different readout chips

Each chip covers 1800 pixels, digital part of the circuitry is at the extremity

The expected fluence is $\approx 2 \times 10^{14}$ $1\ \mathrm{MeV}\ \mathrm{n_{eq}/cm^2}$ for 100 days of operation (sensor center)

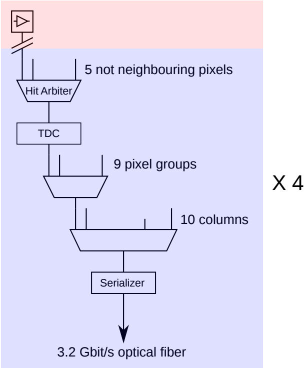
Readout Chip Characteristics

Chip dimensions	$12 \times 19\ \mathrm{mm}^2$
Chip thickness	$100\ \mu\mathrm{m}^\dagger$
Input dynamic range	$0.6 - 10\ \mathrm{fC}$
Electronic noise (with sensor)	$200\ e^-$
Dissipated power (analog)	$\approx 0.4\ \mathrm{W/cm}^2$
Dissipated power (digital)	$\approx 3.23\ \mathrm{W/cm}^2$
Maximum rate per pixel	114 kHz
Maximum rate per chip	130 MHz

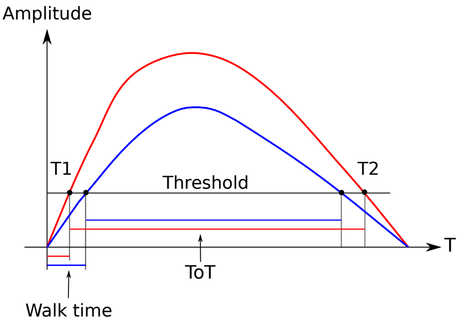
†The final chip thickness with be chosen according to the cooling design

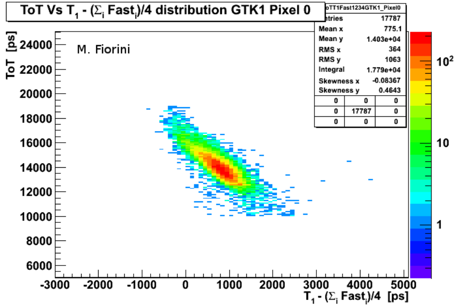
End of column electronics

- Digital and analog part are well separated
- Fast preamplifier-shaper in each pixel, 70 mV/fC gain, 5.5 ns peaking time
- Hit information: leading edge, trailing edge, address and pile-up flag
- 4×10 (columns) $\times$ 45 pixel



Time-over-Threshold



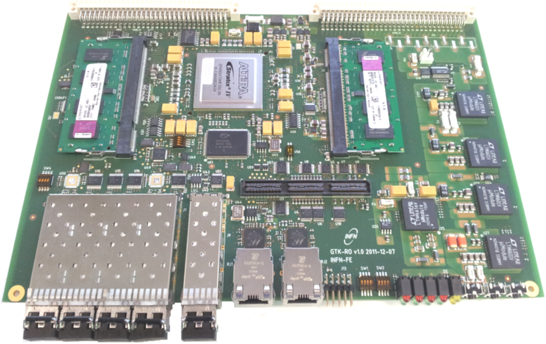


The correction takes advantage of the relation between walk time and time-over-threshold

Data readout

Each chip send data off via four 3.2 Gbit/s optical fibers (40 links per station)

We store the full data-flow waiting for a L0 trigger decision (1 ms latency). We then only keep the data in 75ns window around the trigger.



Micro Channel Cooling

The chips & sensor must be kept at low temperature ($< 5^\circ C$) to cope with radiation damages

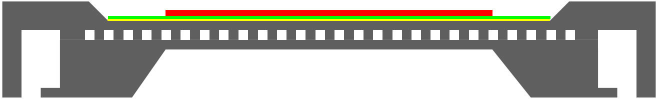
Solution: two bonded silicon wafers with liquid coolant ($\mathrm{C_6F_{14}}$) circulating in micro channels

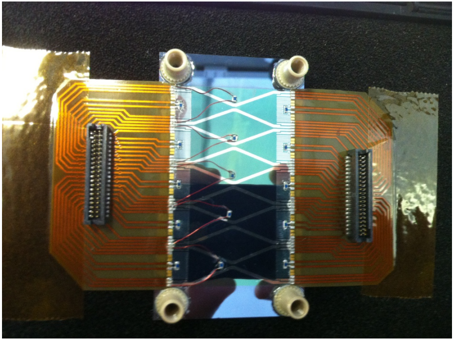
- Low material budget ($< 0.15\% X_0$)
- High thermal stablity
- High thermal uniformity ($\pm 3^\circ C$)
- Reaction time to power/hydraulic failures (time to trigger the power interlook)

Full scale prototype available, characterization ongoing.

Micro Channel Cooling - Baseline Option

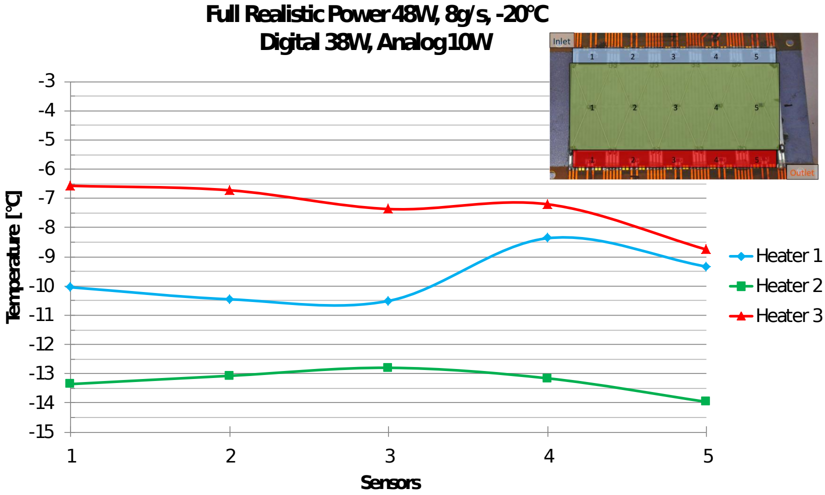
Drawing not to scale: $200 \times 70\ \mu\mathrm{m}^2$ channels separated by a $200\ \mu\mathrm{m}$ wall, $30\ \mu\mathrm{m}$ top and bottom covers.





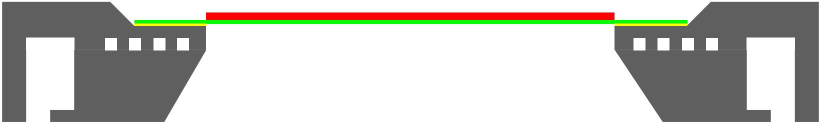
Material in the acceptence area: $0.13\% X_0$

Baseline Option - Results



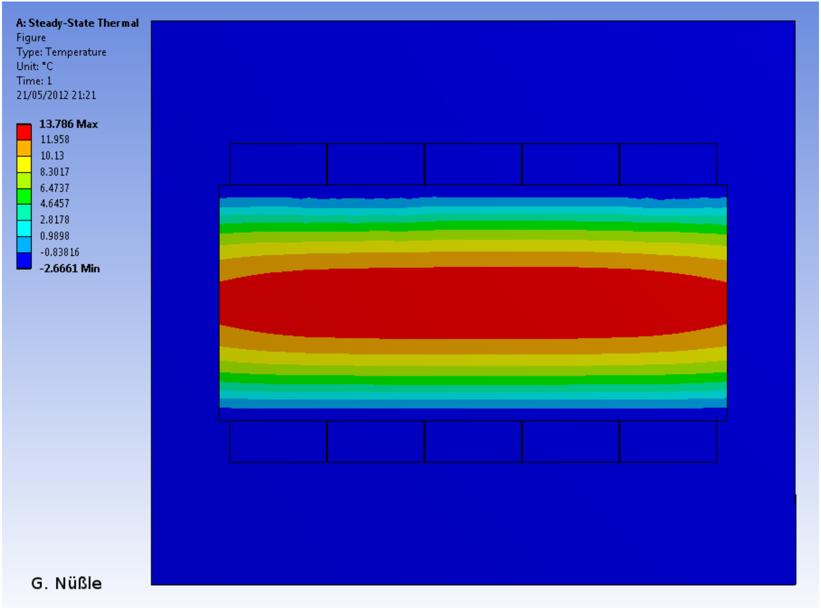
Micro Channel Cooling - Frame Option

Takes advantage of the fact that the digital part of the chip has the highest power dissipation

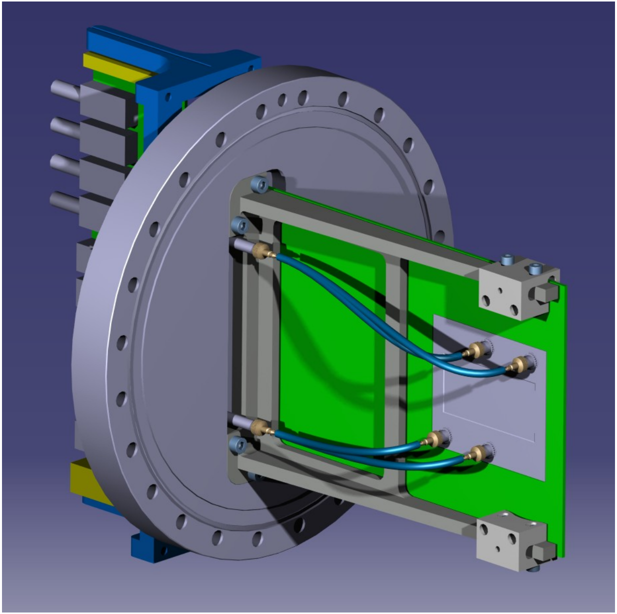


No material at all in the active area but requires a thicker chip to get a reasonable ΔT

Frame Option - Simulation

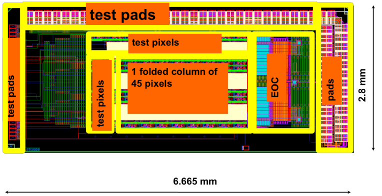


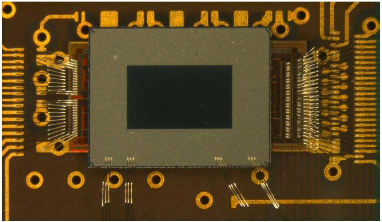
Mechanical integration



Outline

One full column folded into a 5×9 pixel array

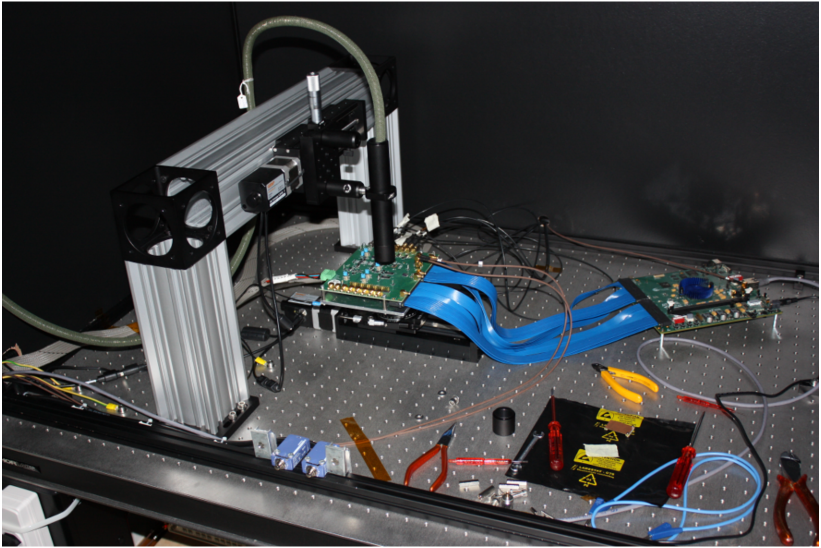




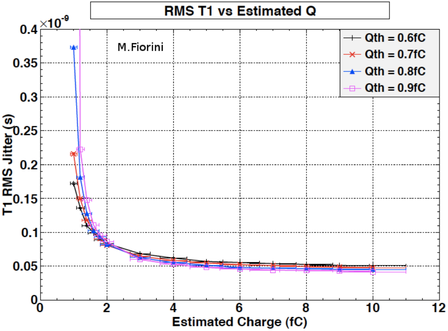
Produced by IBM, bump-bonded and characterized in 2010

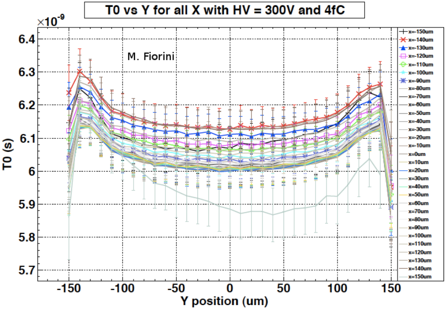
Laser Test Bench

1060 nm infrared laser (mimic MIPs), X-Y scan of pixels



Time resolution of $\approx 75\ \mathrm{ps}$ for 3 fC (MIP) deposited in pixel center

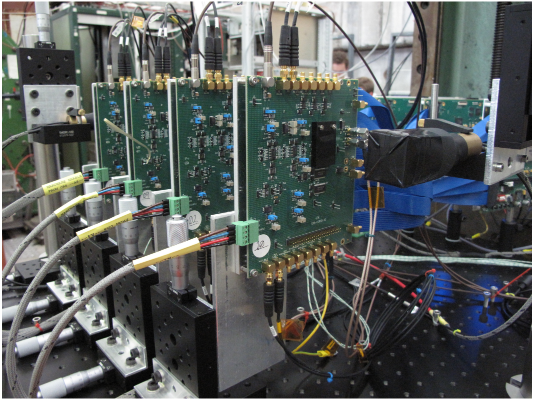




Geometrical dependences due to the weighting field

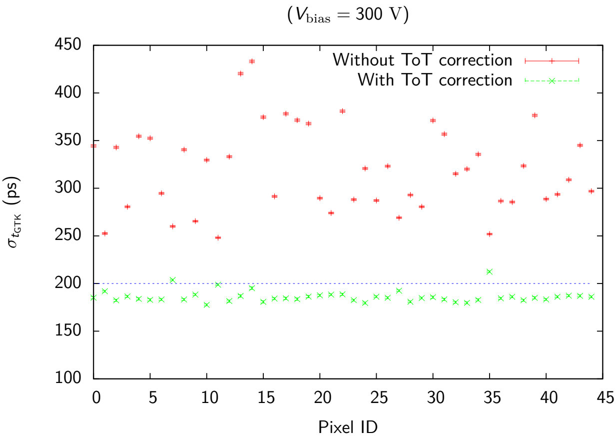
Test Beam @ CERN PS

Test beam in september – october 2010



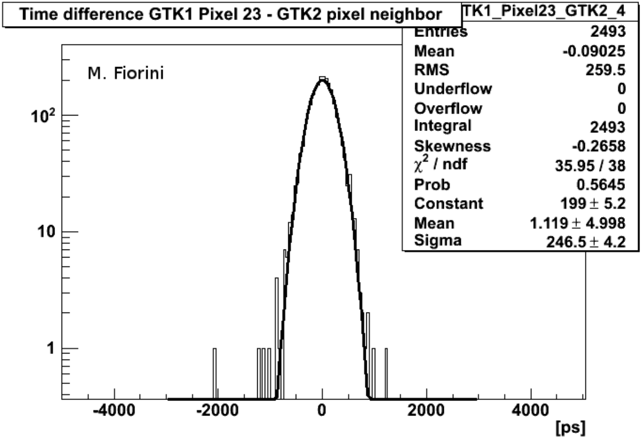
- 10 GeV/c π^+ & p
- 4 GigaTracker prototypes
- Fast scintillators ($\sigma_t = 43\ \mathrm{ps}$) used as timing reference

Test Beam - Main Results (I)



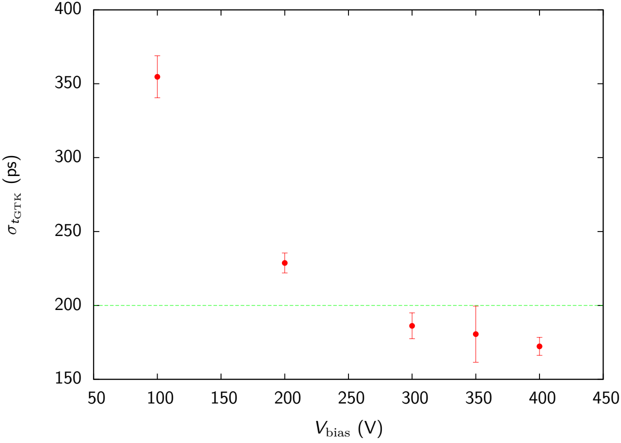
Small variations mainly induced by pixel-by-pixel threshold variation

Test Beam - Main Results (II)



After ToT correction: $V_{\text{bias}} = 300\ \text{V} \rightarrow \sigma_t = 246\ \text{ps}/\sqrt{2} = 175\ \text{ps}$

Test Beam - Main Results (III)



As expected, clear dependence on V_{bias}

Contribution to Time Resolution

- Impact position on pixel,
- Sensor bias voltage,
- Electronic noise of the frontend,
- Energy straggling in the sensor bulk,

Outline

Summary

GigaTracker is

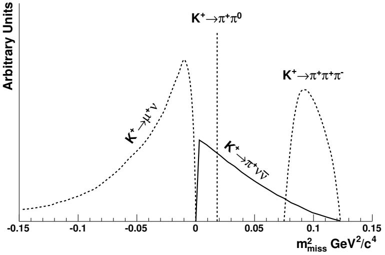
- Fast, $\sigma_t < 175$ ps at $V_{\mathrm{bias}} = 300$ V
- Thin, $X/X_0 < 0.5\%$
- Innovative, it takes advantage of micro channel cooling, the frame option looks promising

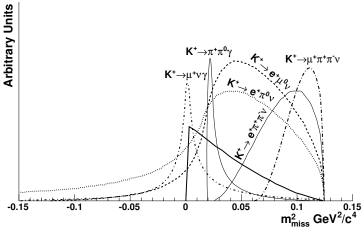
The prototype meets all the specifications and is well tested
We are now building the full scale detector

Backup slides

Background Rejection (I)

92 % of background can be separated from the signal by kinematic cuts (m^2_{miss})





We rely on particle ID (kaons, pions,muons) and photons/muons vetoes for the rest

Background Rejection (II)

- Particle identification
  - Tag the K^+ with **CEDAR**
  - π/μ with **RICH**
- Particle vetoes
  - Photons vetos ($K^+ \to \pi^+\pi^0$ and radiative decays) with **LAV**, **LKr**, **SAC** and **IRC**
  - Muons vetos ($K^+ \to \mu^+\nu$) with **MUV**
  - Inelastic scattering products with **CHOD** and **CHANTI**
- Kinematic measurements with **GigaTracker** and **STRAW** ($K^+ \to \pi^+\pi^0$, $K^+ \to \mu^+\nu$, $K^+ \to \pi^+\pi^-\pi^0$)

Charge Generated In Sensor